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PATENT SPECIFICATION  
DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Continuous Process for Foaming Metal

I, WILLIAM STUART FIEDLER, of 5149, Loruth Terrace, Madison, Wisconsin, United States of America, a Citizen of the United States of America, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

5 This invention relates to the foaming of metal, and more particularly to processes for preparing mechanically strong foams of metal, continuously such as in the shape of endless plates and slabs made from a continuous stream of metal which is poured out at a constant rate, then foams to a substantially expanded size and solidifies to form endless lengths of mechanically strong plate or structural shapes such as rods, beams, slabs or the like.

10 Previously, the foaming of metal has been described but only as a small scale process, based on the mixing in with a measured amount of metal, in a container, of a gasifying substance of some kind, adapted to expand the metal to a foam. From this point to the controlled, continuous process here disclosed, is a great step of development, requiring greatly improved control of the steps and new inventive concepts.

15 The sudden and often almost explosive development of gas which occurs when a molten metal is added to certain gasifying materials in the manner disclosed in some of the prior art, does not lend itself to continuous operation, as it would only result in irregular masses of low and irregular physical properties.

20 I have discovered techniques for carrying out the foaming reactions in such a manner, that the release of gas on foaming is gradual and steady, and is amenable to practical control procedures for the production of continuous and substantially uniform lengths and shapes of foamed metal having tensile

strengths approximately proportional with the amount of metal present in the foam, reduction of thermal conductivity properties proportional with the square of the reduction in weight which has taken place on foaming, and rigidity increased by more than the square of the said weight reduction.

50 In accordance with my invention, I deliberately suppress the foaming in the mixing zone, in which the gas forming material is introduced into the melt of the base metal and feed the material into which the foaming agent has been introduced, but which has not yet foamed to any considerable degree, i.e. before more than 25% of the gas has been released onto a moving member which together with the material moves at a temperature which is sufficiently high to provide for continued decomposition of the gas forming substance and for a time sufficiently long to permit the said metal to attain its optimum foam volume, so that the foaming is carried out while the material is in passive motion, and then lowering the temperature so that the material assumes a solid state and its final form. The said passive motion may be achieved on a moving band, or between a series of moving bands, chains or belts, or it may be in a series of moving form or molds, which are being filled with the mixed, but only initially foamed metal. For the purposes of this invention, I desire to avoid the use of any gas formers which form gas by a sudden or explosive decomposition, such as water on aluminum, or petroleum on molten metals, and I prefer to make use of reactions or gas forming steps which are pressure reversible, so that the reaction does not go to completion at once, but proceeds in proportion to the diffusion of the gas formed and its separation from the solid phase into the gaseous phase. When this is the case, it is not necessary for the purpose of accomplishing controlled retardation of the process to use

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an actual counter pressure, although such may be employed, because I have found that at the point and time of gas separation the partial pressure of the gas will be high enough to retard the further progress of the reaction to practically sufficient degree even though atmospheric pressure prevails in the reaction zone.

For example, petroleum is not a suitable gas former for this invention, because the decomposition of petroleum is determined by the strength and thermal stabilities of the carbon-hydrogen bonds present, and is not greatly affected by small variations in pressure, while on the contrary the decomposition of a metal hydride is very greatly dependent on pressure as well as on heat and so is the gas formation by ebullition of a volatile metal which is at least somewhat soluble in the base metal. In the case of the metal hydrides a pressure difference of one atmosphere may affect foaming by as much as a temperature difference of 50° C. and in the case of zinc, cadmium or magnesium in foaming iron or steels, the pressure dependence of the foaming reaction is equally pronounced. I have discovered that whenever the thermal gas formation is strongly pressure dependent, a possibility exists to bring about the gradual evolution of gas, which is required for a controlled continuous operation.

The invention is further illustrated in the drawings, which are diagrammatic longitudinal sectional views of three different embodiments of the invention.

Referring now to Figure 1, pigs or ingots 1 of aluminum are melted in furnace 2 (wherein for simplicity the heating means are not shown) to provide a more or less continuous stream of aluminum at 3 flowing into holding furnace 5 which is tiltable on trunnions 6 to provide an accurately controlled flow rate of aluminum at 7, being controlled by flowing across weir 8. Aluminum 7 is introduced through tube 11 in a stream into mixing vessel 12. The foaming agent, either as a liquid itself, or dissolved or suspended in a suitable liquid such as a molten metal which is molten below its decomposition point, may be contained as shown at 13, in a reservoir 14, and may be introduced into mixing vessel 12 through tube 15, its flow rate being accurately controlled by orifice 16. It is being interspersed in vessel 12 into the aluminum by mixer 17 driven by motor 18 and is then within a time period preferably not exceeding 10 to 60 seconds, allowed to flow over the edge 19 onto a continuously moving belt 20, where it may take the form of a continuous slab or shape, which moves into the continuous oven 21, at a rate to provide a dwell time for the mixture in the oven of from as short as 5 to 10 seconds to as

long as 6 to 7 minutes. During the time the mixture is carried through the tunnel oven on the belt it is maintained at a relatively high temperature by the tunnel oven and foaming takes place as it emerges from the oven at 22 it cools and solidifies, providing a solid metal foam continuous slab or shaped piece which may be sawed into suitable lengths if desired. The temperatures of the various steps are maintained within the following limits: Transfer from melting apparatus to mixing apparatus: stream temperature 5° C. to 45° C. above mixing temperature; mixing is carried out at from 5° C. above the liquidus point to 5° below the solidus point and the foaming tunnel is maintained at a temperature of from about 300° C. to 5° C., preferably 100° C. to 5° C., below the solidus point, depending on the metal being foamed, the temperature of the interior of the mixture being somewhat higher than that in the tunnel.

Some variations of the procedure shown in Figure 1 are permissible and are shown in Figure 2 which is also a schematic longitudinal sectional view. Molten aluminum β1 is carried in crucible 32 from a melting furnace or other source of molten aluminum and poured into holding furnace 33, wherein, if necessary its temperature may be increased by use of heaters which for the sake of simplicity are not shown or may be reduced by adding small pieces of solid metal. From furnace 33, the aluminum flows outward through tube 34 in a stream into the bottom of mixing vessel 36, its flow being controlled by orifice 35 so as to provide a steady and very accurately controlled and metered flow of aluminum. A suitable foaming agent such as a mixture of 10% of zirconium hydride powder and 90% aluminum powder may be contained inside aluminum tubing 37, which may be stored on reel 38 and fed into vessel 36 in accurately controlled manner by notched rollers 39 which are driven by a motor and gear reduction unit which for simplicity are not shown. As the tube is being introduced into the aluminum vessel 36 which is violently agitated by mixer 40 driven by motor 41, it is melted away as shown at 42 and the foaming agent is dispersed in the aluminum. The mixture is then within about 10 to 60 seconds caused to flow out the upper part of vessel 36 through spout 44 into moving forms or molds 45 which may be carried into oven 46 and may be exposed therein to an elevated temperature for up to 10 minutes before emerging from the oven as shown at 47. In the event that a series of molds are used as shown in Figure 2 rather than the mixture being placed on a belt as shown in Figure 1, it is sometimes not necessary to provide an oven such as oven 46 if the heat capacity of the molds is sufficient and the insulating

quality of the molds is correct to provide the necessary temperature and slow rate of abstraction of heat at the internal surfaces of the molds.

- 5 For some purposes I may also employ the technique of using pressure to retard the decomposition of the foaming material.

In this case we proceed as indicated in Figure 3, which is also a longitudinal diagrammatic view. Here the mixing chamber is maintained under pressure, calculated to depress the decomposition or ebullition of the foaming agent employed, so as to increase the permissible time of dwell in the mixing chamber with consequent improved dispersion.

I provide molten metal 51 by the melting as shown at 52 of ingot or pig 50 by heaters which for simplicity are not shown, and metal 51 is being introduced into the mixing chamber 60 under a pressure achieved either by the weight of a column of molten metal 51 in feeding pipe 53 or by such means as an electromagnetic pump. In similar manner, the solid forming agent 54 is melted at 55 and introduced as molten liquid 56 through feed tube 57 and 58 into chamber 60 under pressure. In chamber 60, the thorough commingling of the metal and foaming agent may be accomplished by operation of beater 61, driven through shaft 62, which may extend through chamber orifice 63, by motor 64. The orifice 63, corresponding somewhat to lip 19 in Figure 1 and spout 44 in Figure 2, is constricted so that pressure is maintained. As the metal leaves the orifice, the pressure is released, and foaming immediately takes place, being quite rapid with some mixtures and less rapid with others. If the foaming is quite rapid, the foam thus obtained may be discharged onto a moving belt either freely, or confined between parallel moving belts so as to give it a desired cross-sectional shape with unlimited longitudinal extension. If the foaming takes place less rapidly, the mixture coming out of orifice 63 may be caused to flow into a belt 65 as shown at 66 and then to pass through an oven such as oven 67 which may be maintained at a temperature from 300° C. up to 5° C. below the solidus point of the mixture to prevent abstraction too rapidly of heat from the outside of the mixture so that the mixture foams within the oven as shown at 68 and upon emerging as shown at 69 cools to provide a solid continuous slab or shaped article of metal foam. Rather than being caused to flow onto a belt the mixture may be discharged into containers or molds mounted on a belt or conveyor and moving therewith and by suitable control of the temperature of the molds as described in connection with Figure 2 may be caused to foam therewith so that

this means a continuous production of foamed metal is achieved.

The following examples are given to illustrate the invention, but are not intended to limit it in any way:—

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## EXAMPLE 1

Into a stream of molten aluminum having a temperature of 690° C. is fed a stream (molten liquid) of a dispersion of 10% of titanium hydride in 90% of an alloy comprising 32% aluminum and 68% magnesium. The ratio of said streams is 9 parts of aluminium to 1 part of the dispersion and the temperature of the said second stream is 440° C. Immediately after the commingling of said streams, they pass through a vessel in which very strong agitation is effected by means of corrugated disc type agitator revolving at 6000 rpm. From this, the metal mixture which is now just beginning to foam, flows onto a steel belt conveyor, which has been treated with lime to render it more heat resistant, and moves with this conveyor into a heated tunnel. The speed of flow is regulated so that the foaming which takes place between the intermingling of said streams and the moment the metal is deposited on the said moving belt is less than 25% of the potential total foaming of said metal, as measured by the extent of volume expansion realized at that point in relation to the maximum volume attained. The time in which any given part of the metal passes from the point of intermixing of metal streams to the said moving belt is less than 10 to 60 seconds.

The temperature in the said tunnel may be controlled so that the temperature of the metal is 630° or from 400° C. to 650° C. at the middle of the tunnel, and 600° or from 300° to 620° C. on leaving the tunnel, the time of passage being 280 seconds or from 80 to 600 seconds. After emergence from the tunnel, the metal foam is being cooled by means of air jets, so that it is rapidly brought below the temperature at which deformation can occur.

The cooling may be effected with either air jets or by water jets.

The resultant metal foam had a width of 25 centimeters, a height of 10 centimeters, and an unlimited length, being produced in continuous operation, limited in length only by the desire to cut off the foam slab when this reaches the remote end of the factory.

## EXAMPLE 2

Aluminum metal and 1/2% by its weight of zirconium hydride are mixed together in a pressure furnace at a pressure of 100 atmospheres and a temperature of 940° C. The pressure prevents gas release from the hydride. The metal-hydride mixture is released in a steady flow into a series of

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- molds, which are moved past the opened orifice on a chain conveyor. On release, the hydride begins to decompose, and continues to decompose as the molds are moved through a heated tunnel, which may be of 30 meter length, with the molds moving at a speed of 10 meters per minute or from 4 meters to 40 meters per minute. At the end of said tunnel, the molds may be passed through a bath of boiling water, in order to bring the temperature to the solidification point of the metal and to prevent such collapse of the foam as would take place if it were kept too long at a softening temperature.
- 15 The temperature in the said tunnel during the passage through said tunnel of the said metal in the molds is maintained within the ranges as set forth in Example 1.
- 20 While reference has been made in the above examples to certain specific metals and conditions, other metals and combinations may also be employed. For example, the principle of foaming in continuous process by the use of a reversibly released gaseous
- 25 substance, capable of relatively slow and controllable release, in conjunction with a mechanical manufacturing cycle adapted to utilize these controllable properties for continuous foaming, can be adapted to many metal systems. For example, the ferrous metals and alloys, cobalt, nickel, copper, titanium, zirconium, niobium, and also the low melting metals such as lead, zinc, lithium, aluminum and magnesium and alloys thereof
- 30 lend themselves to these processes. Generally speaking, the metals melting below 1200° C. are preferably foamed by means of the hydrides, such as zirconium, titanium, lithium, lithium aluminum, and magnesium
- 35 hydrides, while the metals melting above 1200° C. are generally preferably foamed by means of a metal which has a boiling point below 1150° C. at atmospheric pressure, or, in the case of the very high melting metals,
- 40 45 a boiling point well below their respective melting points, and which can be made to remain liquid at the operating temperatures in question by the application of pressure.
- I have found that the foaming of the
- 50 metal should be carried out as far as possible in its final position, that is when the foam is at rest in relation to its immediately adjacent surfaces. If the metal is exposed to skin friction while foaming, by motion of the foam in relation to the surfaces which it contacts, not only does the foam tend to break, but the remaining foam cells become irregular and distorted, and do not have the mechanical strength which is characteristic of the foams made in accordance with this invention. It is therefore necessary to bring the metal onto a moving surface or surfaces before more than 25% of the foaming has taken place, and to carry out the main portion of the foaming when the foam-
- ing metal is being carried passively by a moving carrier surface, and without any motion of the foam in relation to the said carrier surface. For this reason, I prefer to form any structural members of specific cross-sectional shapes by casting the metal between moving belts or other moving surfaces, so that the metal while it is foamed, is stationary in relation to the said adjoining surfaces, and not to form such cross-sectional shapes in the conventional manner through extrusion through dies.
- As a practical manner, I prefer to bring the metal from the mixing stage to the moving belt in a time no longer than 10 to 60 seconds, and preferably substantially shorter than 45 seconds.
- As for the temperature of the foaming zone, I prefer to keep this within the range of between from 10° to 200° above room temperature and a point 5° to 300° C. below the solidus point of the said metal composition.
- WHAT I CLAIM IS:—
1. A continuous process for manufacturing foamed metal, in which there is fed into a molten base metal, a substance capable of gradually releasing gas at the temperature of the metal melt, with mixing so as to cause thorough commingling of said metal and the gas releasing substance, and in which the said mixture is then rapidly, before more than 25% of said gas has been released, brought into conjunction with a moving member so that the mixture is brought substantially to rest in relation to such moving member, the mixture then being moved with the moving member at a temperature which is sufficiently high to provide for continued decomposition of said gas generating substance, and for a time sufficiently long to permit the said metal to attain its optimum foam volume, the temperature of the resultant metal foam being then lowered sufficiently to cause it to solidify.
2. A process as claimed in Claim 1, in which the said gas releasing substance is fed continuously into a flowing stream of said base metal.
3. A process as claimed in Claim 1, in which the said gas releasing substance is intermixed with the said base metal under a pressure sufficient to prevent the said gas release, until the said mixture is released from the said pressure vessel.
4. A process as claimed in any preceding claim, in which the said gas releasing reaction is reversible, and pressure dependent.
5. A process as claimed in Claim 3, in which the base metal has a melting point above 1200° C. and the gas forming substance is a metal having a boiling point at atmospheric pressure below 1150° C.
6. A process as claimed in any preceding claim, in which the base metal is aluminum,

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- zinc, magnesium, lithium, lead or an alloy thereof and the gas forming agent is a metal hydride.
7. A process as claimed in any preceding claim, in which the time interval between the addition of the gas forming agent and the discharge of the mixture onto the said continuously moving member is 10 to 60 seconds, and in which the mixture travels while foaming through a heating zone the temperature of which is between 5° C. and 100° C. below the solidus point of the mixture, the temperature in the interior of the mixture being somewhat higher than said zone temperature.
8. A process as claimed in Claim 2, in which said gas releasing substance is in the form of a molten stream or is contained in a molten stream.
9. A process as claimed in Claim 2, in which said gas releasing substance is in the form of a powder.
10. A process as claimed in Claim 9, in which said gas releasing substance in powder form is commingled with a metal powder.
11. A process as claimed in Claim 9 or 10, in which the powder is contained within a metal tube which is continuously advanced into said molten metal.
12. A continuous process for manufacturing foamed metal substantially as hereinbefore described with reference to the accompanying drawings and/or either of the foregoing examples.

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Agents for the Applicant.

Reference has been directed in pursuance of Section 9, subsection (1) of the Patents Act, 1949, to Patents Nos. 811,814 and 729,339.

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FIG.1

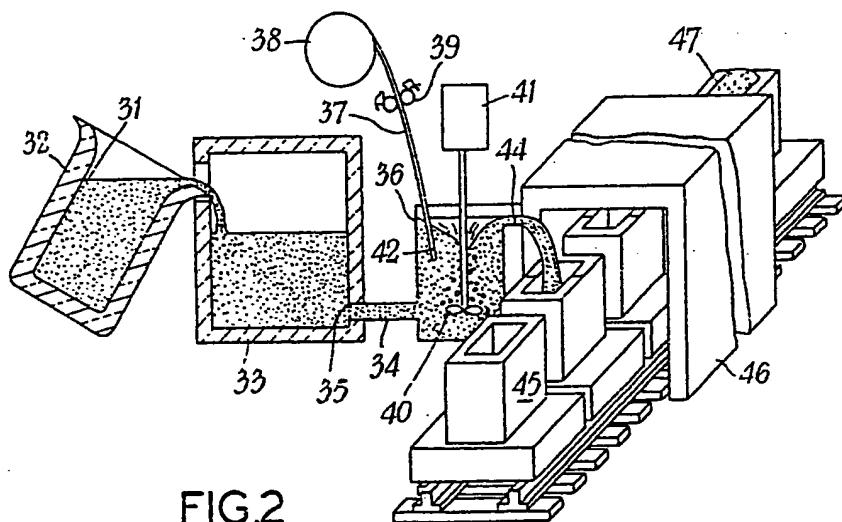
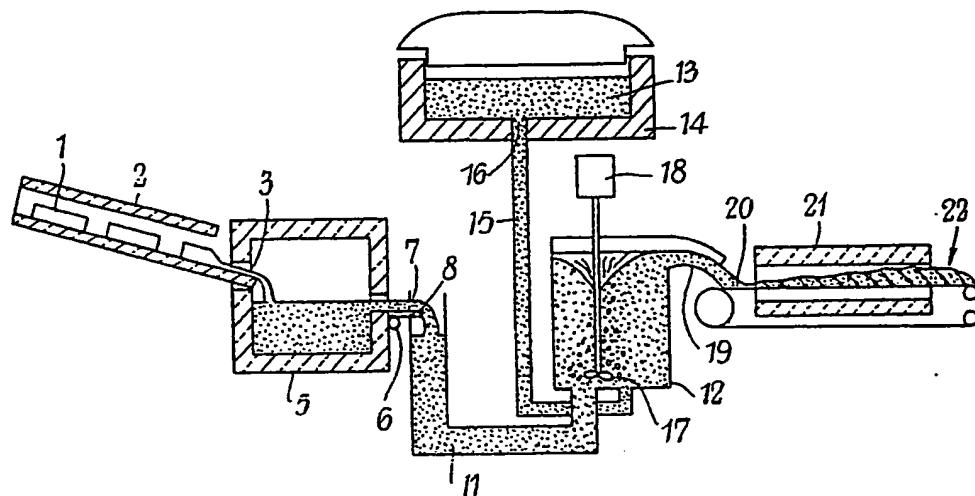
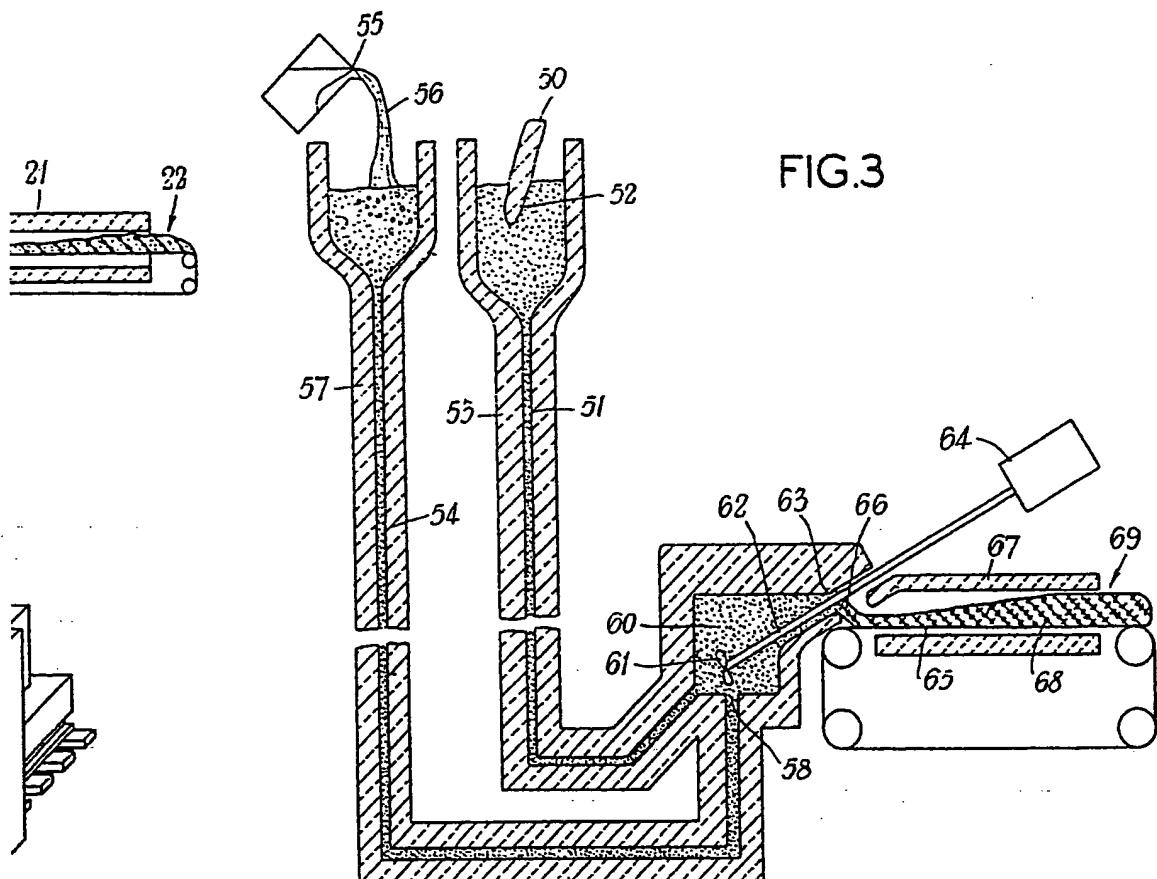


FIG.2

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the Original on a reduced scale.  
SHEETS 1 & 2



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SHEETS 1 & 2

FIG.1

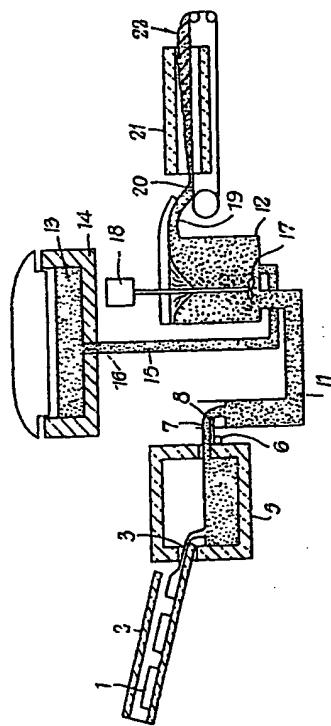


FIG.3

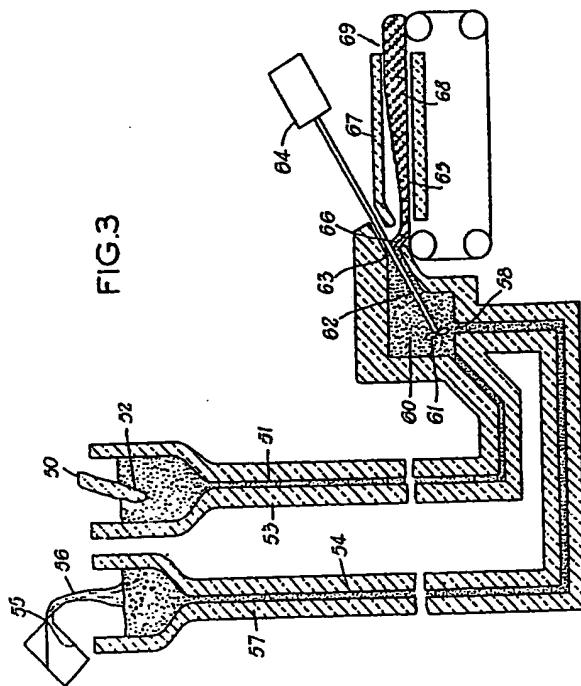


FIG.2

